Additions and Modifications to the Igneous Rock Classification Scheme

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Abstract

Igneous rocks as they are currently defined are in a sloppy state. Vague wording is throughout the whole of the definition, and there is not even any clear consensus on what it should be defined as. In this paper, I redefine igneous rocks in such a way as to remove a great deal of imprecision, and I go through some of the logical implications of the refined definition. I do not seek to change the intent of the definition, and I do not believe that I have. The most interesting implication of this change is that water, as it occurs on Earth, is an igneous rock, and I construct a basic classification scheme for it.

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The current system for classifying igneous rocks is very narrow in its scope. The primary diagram, the QAPF (Quartz, alkali feldspar, plagioclase feldspar and feldspathoid), focuses on rocks with normal-to-Earth compositions and a silica content of about 45% or higher. This leaves many possible combinations without any sort of guide to classification. Thus the current system needs to be expanded, not only in specific rocks that are covered, but also a framework needs to be developed in order to classify any future additions. I will set up the basic framework for the classification, and I will go into detail about how it applies to water, creating a diagram for it.

I should first begin by clearly defining what an igneous rock is. The definition of a rock, as per the Glossary of Geology, pg. 558, as “an aggregate of one of more minerals, e.g., granite, shale, marble; or a body of undifferentiated mineral matter, e.g., obsidian; or a lithified organic material, e.g., coal.” This definition opens up many different things to fall under the classification of what a rock is, and is not always clear. However, that is beyond the scope of this paper, and I shall table that discussion. Instead, I shall focus on the word igneous. The current and most accepted definition, as I understand it, is something around “any rock formed from the cooling of a molten material into a solid phase.” Specific definitions include “Said of a rock or mineral that solidified from molten or partially molten material, i.e. from a magma” from the Glossary of Geology, pg. 320: “Igneous petrology relates to the study of rocks that solidified from hot, molten or partially molten material, i.e. igneous rocks” from The Encyclopedia of Igneous and Metamorphic Petrology, pg. 229: and from The Concise Oxford Dictionary of Earth Sciences, pg. 189 “rocks that have crystallized from a magma.” Even Wikipedia, in their article on igneous rocks, say “Igneous rock is formed by magma or lava (molten rock) cooling and becoming solid.”

I find these definitions all to be woefully imprecise. The definition of molten, as per the Oxford English Dictionary, that best approximates the intent for igneous rocks is “Chiefly of metal, glass and rock: liquefied by the application of heat; in a state of fusion. Rarely applied to substances that are liquid at normal temperatures, such as water obtained from melting ice.” I believe that this in science is unacceptable. At what point is something molten? At what point is it not? Unclear cutoff points create room for purely subjective interpretation, which if at all avoidable, should be so avoided. Thus, molten needs to be removed from the definition. At first I considered changing it simply to liquid from molten; however I think that one more expansion is required. It should be set to fluid, as there is currently no means to classify rock that formed from deposition of gas to solid phase. This is still not quite specific enough; not all rocks that contain a fluid component had at some point been igneous rocks. Whenever a small portion of a sample melts down, and then cools to a solid again, it is generally considered a migmatite. This is a useful distinction, as it avoids distraction from what a sample primarily is: a rock where a small portion melts while the rest is simply modified by the heat is dominated with metamorphic processes, not igneous ones. Thus, there should be a clear cutoff for when a sample is igneous, and when it is metamorphic. The clear and simple choice is 50%: when more than 50% of the sample melts, it is now an igneous rock; when less than 50% melts, it is a migmatite[*]. Finally, simply to say “to cool from fluid to solid” opens up liberal interpretations about a precipitate that only forms when the solution in which it is contained cools. Samples that had precipitated out of a solution are already covered under sedimentary rocks. A decision must now be made on how to split up the rocks that fall into both jurisdictions. Since the expansion of the igneous domain

[*]This raises an interesting question; what to call the unmelted rock within the migmatites or within the igneous rocks with portions of the source rock remained solid. It is clearly not a xenolith, for it is not a piece of country rock; it is still part of the rock that did melt.

is what caused the overlap, sedimentary should get precedence over the rocks in question. This does not mean that no other concerns apply, just that all else being equal, the less change that is made to the definitions and classification schemes the better.

Another concern that should be taken into account is the intent of my change; I wish to include rocks that undergo a physical change to form, for as I see it the chemical change jurisdiction is already covered quite nicely by sedimentary. This leads me clearly to the final change that must be made to the definition; a specification on how the rock sample changes from a fluid to a solid state. Therefore, I should say rocks that form from the phase change from the fluid phase to the solid. This brings the final definition to "any rock primarily formed from the phase change of a fluid to a solid." This new definition opens up new interesting possibilities of what is an igneous rock, and lends classification to rocks that were not clearly under any group previously.

Next, I shall go into detail on what these diagrams are, and what they should be.

These diagrams are built around the presence of minerals in a sample being sufficiently abundant so as to allow the determination of the modal mineral content, and are thus devised not to be an absolute scale, chemical or otherwise, on which to name rocks. Instead, the diagrams are a useful tool to which all geologists can refer, such that they can communicate clearly about any given sample. Therefore, these systems should never be created around an absolute chemical scale, as that would be going against its purpose. To clarify, an absolute scale of percentages of elements contained within the sample would be counterproductive to the naming of rocks; two samples may have different modal mineral content but the same chemistry, and vice versa. It still is useful to geologists, however, to understand what chemical compositions will form what general modal mineral contents. This is because it is easier and more time efficient to determine a rock's name from its chemistry than to always go by modal mineral content, especially in a lab context. The modal mineral method will always be more useful when identifying a sample in the field, which is of course the point. In addition, the scales should have clearly defined end members, along with clear boundaries between each rock type within the diagram. The different rocks should be defined around the modal mineral composition, of course, but these said boundaries should be chosen for some other clear reason. Such reasons include a sudden shift in average physical properties of the sample or a dramatic change in depositional behavior.

Also, because these scales are created in order to facilitate communication about rocks, the scales should never need to incorporate purely theoretical rocks: this is not to say that there is nothing to be gained from experimenting with hypothetical assemblages of minerals, just that it is not important enough to geologists working in the field for it to be included in these schemes. Therefore, it also does not suit geology to force groupings of minerals together which have not been observed together in the field, and also those which did not form together, as that would require theoretical rocks to fill in the boundaries. This would also add an implication of relation of the two types when there in fact is none, which would only serve to confuse those using the diagram. Any additional assemblages observed may be added at a later time, but it does not serve the general science to make anything up ahead of time. Finally, any diagram needs to be clearly defined under what conditions it is appropriate to use. Temperature and pressure under which the rock formed, along with the chemistries of the samples that are covered within it, should be part of any such graph. As new distinguishing factors arise, these too should also be included in the description of the diagram. I will now demonstrate how these criteria apply to the current dominant diagrams.

The current system for classifying igneous rocks is the QAPF diagram, so named after the 4 minerals that make up its corners: quartz, alkali feldspar, plagioclase feldspar, and feldspathoids (foids).

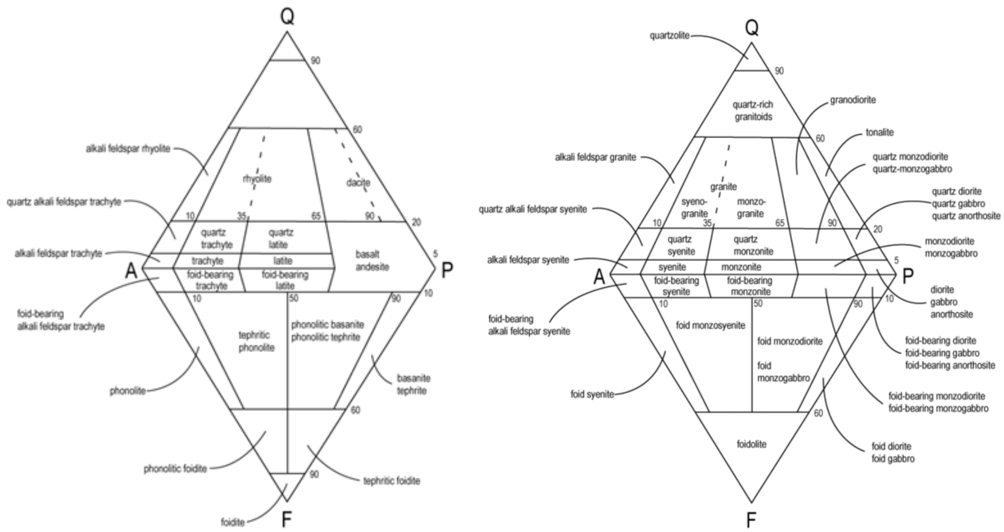

Figure 1. Both of these images are sourced http://en.wikipedia.org/wiki/QAPF_diagram with the image on the left being that of fine grained minerals and the one of the left being for large grained minerals.

This leads to a diagram suitable only for samples that contain ~45% silica or more (Figure 1). The diagram is then divided into two broad systems, based on the size of the crystals found in the sample: one where the rocks display large phenocrysts, generally because they are intrusive, and those that have fine groundmass and small phenocrysts, with these usually being of the extrusive variety. The current models are set up at Earth normal temperatures and pressures (from melting at the bottom of the lithosphere to cooling in the crust), with the aforementioned silica content that is standard for the magmas and lavas that occur within the lithosphere and crust. The two varieties of the QAPF diagram are distinguished based on cooling times through the measurement of phenocryst size.

Though not clearly defined in the literature, it does appear to be the case that the QAPF diagrams meet the criteria for being clearly set out, simply as a factor of their creation. However, the existing QAPF diagrams do not cover all of the other fluid materials that occur on Earth that undergo a phase change to a solid under natural conditions. Other compositions occur on Earth as magma, and sometimes even interact with the silica based magmas. However, the vast majority of magmas occur as these silica based magmas, and the majority of them are not mixtures with these more exotic varieties. Since most of these silicate magmas occur without others, along with my premise that diagrams should not be created to classify theoretical rocks, the current diagrams should not be changed, as they fulfill their job nicely.

Examples of more exotic geological fluids include carbonatite and kimberlite lavas and magmas: these occur on Earth, and they also sometimes mix with the more abundant silicate magmas. Whenever this mixing becomes dominant, as it does for the carbonatite magmas, then it is a significant factor in the occurrence of these magmas and should be taken into account in the formulation of the diagram. This does not mean that it should actually be on the diagram; it may mean simply that it should be noted in the name of the rock when the final name is determined. For example, a carbonatite with quartz that formed with it, a quartz that is not a xenolith, may be simply called a quartz bearing carbonatite. Now I shall move on and discuss all the possible candidates for being an igneous rock, and set forth some guidelines on how to create the diagrams in the future.

There are many different possibilities for what can be an igneous rock under my new definition, but I will begin by focusing on the compositions that were already considered igneous and how to classify them, these of course being kimberlites and carbonatites. Both of these magmas occur under conditions similar to those for normal silicate magmas, and can therefore be classified in a similar manner. The only real quality that sets these magmas apart from other, more exotic varieties is that we know a special circumstance that will potentially apply to them; that they mix with normal silicate magmas. If the primary occurrence of the kimberlite or carbonatite magma is in a mixture with normal silicate magmas, then the diagram should take this into account somehow. This could mean that silicate magmas are actually on the naming diagram, where one of the end members in associated with it, or that clear rules have been established for naming the mixture of the two magmas.

This brings me to another point: igneous samples need to be named on what makes up, if not a majority, then a plurality of a sample. This only applies to components that had been in fluid phase together at some point before solidifying, and those that are completely incompatible, such as carbonatites and silicates. Other samples, where one chemical group does not melt, should simply be classified as xenoliths, as they already are. For more general rules, these systems should also be based around the primary chemical compositions: since silicate is the primary anion for the current system, carbonate should similarly be the basis for the carbonatite lavas, and silica should also be the basis of the kimberlite systems. Even though there is already a silica based system, creating another one for the kimberlite group seems required as it is still the basis of the minerals that make up kimberlites. This could extend on to other igneous rocks made of other base materials. My thoughts turn to other planets and other locations in the universe with different conditions from our own. There could be sulfur based igneous rocks, methane based, gold based, iron oxide based, *ad nauseum*. The potential exists for infinite systems, but I still hold that systems for theoretical compositions should not be made under the scope of this project; only known igneous rocks need to be covered. One of these known igneous rocks that is not covered by any of the current diagrams is water ice; this is not commonly held to be igneous, or even a rock-forming mineral, so I will first defend my claim and move then onto a classification diagram.

I shall first restate the definitions of rock and mineral, for they apply directly to the question at hand. Rock is defined as above, while mineral is defined, according to the same text, the Glossary of Geology, pg. 415, as "a naturally occurring inorganic element or compound having a periodically repeating arraignment of atoms and characteristic chemical composition, resulting in distinctive physical properties" and also as "an element or chemical compound that has formed as a result of geologic processes." Following from these definitions, ice must be considered as a rock-forming mineral. It is naturally occurring, inorganic, has a chemical formula of H_2O, and occurs in a hexagonal crystal structure. Large chunks of ice must then be considered as a rock. After this, the type of rock must be determined. I will only concern myself with what occurs on the surface of the Earth, for the moment. I do not have enough information to make any reasonable diagrams for how it occurs outside of Earth systems. Generally speaking, water occurs as ice on Earth's surface by phase changing from a fluid to a solid, putting it firmly within the realm of igneous rocks, as I detail below.

Water ice, as it forms on Earth, is clearly an igneous rock. It forms from a liquid phase changing to a solid phase, with two primary methods of accumulation on Earth. The first is gaseous phase water in the atmosphere condensing around some particle in the atmosphere, and then freezing solid. From there it falls to Earth and accumulates on the surface. This reminds me of nothing more than tuff beds being formed from volcanic eruptions, with the only real differences being the delivery system to the atmosphere and the fact that the water generally starts in a gaseous phase before becoming liquid. In volcanic eruptions, small particles of liquid lava are ejected into the air, where they quickly solidify and fall to the Earth as ash, forming tuff beds. Thus, snowfields should be classified as tuff beds. Another similarity snowfields share with traditional tuff beds is that they sometimes undergo welding, where the material partially melts again in order to fuse together into one coherent unit. The other primary deposition of water ice on the surface is when standing pools of water are able to cool and solidify. This is very similar to how pools of lava, generally but not exclusively within calderas, cool to solid rock. There are, of course, the differences between that the fact that water ice floats on top of the liquid phase instead of sinking, and the fact the water comes to be within its collecting pools in a different fashion than the silica lava, but this does not change the simple fact that the ice still meets all the criteria for an igneous rock. Now I shall go into a framework and a diagram for classifying these water ice igneous rocks.

I shall begin with how ice occurs on Earth. I have already stated that it comes down in snowfalls and then also freezes from standing bodies of water. These primarily happen on a cyclical nature, with a yearly freeze/thaw. This is, of course not the end of it; many forms of the ice persist for thousand upon thousands of years. However, the lifespan for these samples is still geologically short, and that fact still remains that they are not stable as rock on a great deal of the Earth; burying ice to any significant depth or heating ice to any moderate Earth temperature will cause it to return it to a liquid state, making it clearly no longer a rock. This means that the rocks that form from ice do not co-form with any other rock on the earth, or even any other mineral, in an igneous manner. Thus, it does not need to be on a diagram with any other minerals, or even any other chemicals; water forms as a mineral all on its own.

Thus, we need some other sort of delimiter to distinguish between different types of water as a rock. I think that it should be built around what type of inclusions water ice can have, as water ice also does not vary in crystalline structure on the surface of the Earth whatsoever.

Common inclusions that I think are important are fluids, biological fragments and pieces of other, already formed rocks and minerals. I cannot come up with any other thing that distinguishes water chemically or physically from other instances of itself, so I will base my diagram off of it. This will not cover where the ice is located whatsoever, like the QAPF diagram, so that I will not distinguish if this type of ice formed on the top of a lake or in the atmosphere to fall upon a mountainside and create a glacier, at least on the base diagram. However, I could, and I think I should, differentiate between them in another fashion, taken from how the QAPF diagrams do it: have two separate diagrams, with one for material that forms from precipitation, and the other from standing water freezing into a solid state. This does not, of course, create the diagram. I think that the diagram, following from the points outlined above, should be built as a triangular pyramid, in three dimensions. The top point of the pyramid will represent pure water ice, with each of the three bottom corners representing fluid inclusions, solid organic inclusions and xenoliths, with a percentage scale along each edge going from a pure one substance to another. This diagram applies only at this point to water ice that occurs on Earth, with the potential to be applied to other planets with similar systems to Earth; none is known as of yet. This could potentially open up issues with a pile of organic material ending up on the diagram: however, anything that does not fit the definition of the rock would not be on the diagram in the first place. Organic material the does not contain ice at all is not lithified in any sense, a standing pool of liquid is not a solid body, and an assemblage of other rocks and minerals without ice have no place on this diagram either. I should be clear to state that to fit on the diagram, water ice must be included, and any given object that is to be called an ice rock should have ice holding the sample together. This brings up another point: saying ice rock is awkward and clumsy, when a new or multiple new terms would be more appropriate.

Having clearly defined ice as a rock-forming mineral, we come upon a group of rocks that are not commonly acknowledged as rocks. I believe this is because they are not always in rock form on the surface, commonly melting down and refreezing. Thus, a new term should be coined to recognize the fact that these rocks exist, and are different from other rocks. I propose simply cryolith, for the words parts are simple and know, and the meaning is almost self evident; cold rock. This would have two alternate definitions as I see it. The first would be any rock that only exists at below Earth normal temperatures. The second being any rock that only can exist at temperatures below the average of the system they form in. On Earth these would be the same, but on other planets they would be very different from those of Earth. I support the one about cooler than the system they formed in, as it will change in absolute meaning from system to system, the relative meaning will always stay the same. Its counterpart, thermolith, will be an interesting object indeed, a rock that only can exist at temperatures above the average of the system in which they occur. I cannot think of any rock that would qualify as such, as this definition is not taking into account pressure at all, and I am not certain how it would apply to samples in the mantle and deeper of planets. Then, we come to ice. It needs its own clear name as a rock, for ice as it is used today can mean it in any context, including artificially generated, making it clearly not a rock, and also ice can apply to other things than water. I propose the term glaciolith, for it contains recognized words parts, and it translates to something approximating to "ice (implied water) rock". This brings me to naming the different rocks inside the pyramids of my diagram, and I will use the term glaciolith as the base. Therefore, the rocks that occur near the top of the pyramid, that are close to being pure ice, should be simply referred to as glaciolith s. Ones with a great deal of fluids trapped in them should be called, simply vesicular glacioliths, ones with many sub-fossils should be called sub-fossiliferous glacioliths, and the ones with a great deal of xenoliths should be called xenolith bearing glacioliths. The distinction between the two graphs need only be that the source for one is precipitation, while the other results from the solidification of standing water on Earth. To advance to my final point, the fact that ice needed to have the term cryolith coined in order to cover it is a clear indication that something is strange with it, compared to other rocks. The point I am getting to is that lava, defined by Glossary of Geology, pg. 364, as "a general term for molten extrusive; also, for the rock that is solidified from it," does not cover ice as it occurs on Earth.

In addition to my dislike of the term molten, I have issues concerning the definition of lava. I am choosing not to redefine it at this time, as it should be the topic of another paper. However, I do agree with the part about lava being extrusive material, that is, material that is extruded onto the Earth's surface which then cools to a solid to form an igneous rock. Water does not behave in this way. It is emitted from volcanic vents, but then it generally does not solidify for some time. In fact, it goes into a gas phase, and can cycle many times between liquid and gas before it ever becomes solid. I think that the term lava, even when it is clarified, will not cover this behavior. Thus, I will introduce one final term in this paper, that of nara. The origin of the terms lava and magma seems very disparate, and the importance seems to have been placed not on the source, but on how the terms looks; its style, if you will. Thus, I choose nara as a term that fits the style. What it actually describes is the fluid phase of what can become an igneous rock that cycles while on the surface and can enter the atmosphere. So, as it applies to the Earth as a whole, all water can be considered nara. In the context of a equatorial lake, it is not; the water will never solidify into an igneous rock in this context.

Conclusions

I have shown how the definition of igneous rock was imprecise, redefined it, and plotted out some consequences of the change. I hold that I have not changed the intent of the term, only the wording, in order to make for a more defined science as a whole.

Further Work

More definitions should be looked at. As I spoke of, lava, and also magma, are very imprecisely defined as it is. Mineraloid is also a little vague, as is rock. Going from definitions, there is also the fact that there are many other rocks that fit the definition of igneous rock, and thus need a classification scheme for them. Pure elements like sulfur, methane on other planets, heavy elements left over from a supernova, the potential diagrams are limitless.

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